The U.S. Department of Energy - Federal Energy Technology Center
Climate Change Fuel Cell Program

Ramapo College of New Jersey
Two (2) – 200 kW Units

Final Report

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Abstract

Two 200 kW Fuel Cells were installed at Ramapo College of New Jersey in Mahwah, New Jersey, in the year 2000. One fuel cell ("Dormitory Fuel Cell") was configured to operate in parallel with the electric grid for the supply of electricity to a new student dormitory. The fuel cell was also installed to supply thermal energy to the dorm's domestic hot water and space heat systems. The other fuel cell ("Academic Fuel Cell") was configured to provide electric power in parallel with the grid to the College's core academic building complex. This fuel cell has the capability to provide power, in case of electric grid failure, to the College's computer center, telephone exchange and cable TV station. Thermal energy from the Academic Fuel Cell supplies the building's hot water space heating system.

The two Fuel Cells have operated satisfactorily over the past year. Several unscheduled shut downs have occurred because of high operating temperatures. These problems were solved with minor repairs. Fuel Cell operating availability has exceeded 98 % for both units and overall electrical production and thermal efficiency has met projections. The Dormitory Fuel Cell electrical output was reduced to 100 kW to reflect the reduced base load demand of the dormitory during part of the year and to prolong the life of the cell stack.

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Executive Summary

Two IFC Model PC 25C fuel cells were installed at the campus of Ramapo College of New Jersey in 2000. Each fuel cell can provide up to 200 kW of electric power. The goal of the project was to provide economical and environmentally benign electrical and thermal energy to the campus and to provide backup power to a host of critical loads around the campus. Both of these goals were accomplished.

The first fuel cell provides electrical power and hot water to a new dormitory building on campus. The fuel cell provides electric power in parallel with the electric grid during normal operation. Upon grid failure, the fuel cell disconnects from the grid and awaits manual reset.

Hot water from the fuel cell is pumped to the dorm's domestic and space heating systems. When the base load of the dorm was discovered to be less than 200 kW the fuel cell output was reduced to 100 kW to avoid feeding power into the grid. In all other aspects, the operational availability and efficiency of the unit conforms to initial projections.

The second fuel cell provides electrical power and hot water to a core group of academic buildings. As with the dorm fuel cell, the academic fuel cell operates in parallel with the electric grid. Upon grid failure, the fuel cell automatically disconnects from the grid. Within 10 seconds of grid failure, the fuel cell will reconfigure itself and provide electrical power directly to individual electrical panels. The electrical panels provide power primarily to the college computer center, telephone system, and cable TV station. This ability to reconfigure and power individual loads is one of the primary benefits of the fuel cell.

Operational availability and system efficiency for both fuel cells conforms to initial projections. Installation costs were much higher than projected because of the large number of academic fuel cell loads wired for power upon grid failure and because the location of the dormitory fuel is over 300 feet from the thermal and electrical connections.

The total cost of the two fuel cells including installation was $2,150,000. Of this cost, approximately $1,300,000 was attributed to the fuel cells themselves with the remainder allocated to installation labor and auxiliary equipment, design and project management.

Introduction

Ramapo College Environment

Ramapo College is a state Chartered Liberal Arts College located in Mahwah, New Jersey. The college maintains a Cable TV station and distribution center, various telephone exchanges and a large computer center. Rockland Electric Company provides electric service and PSE&G provides natural gas service to the College. During the fall and winter of 1998, the college was concerned about the reliability of the electric service. In particular, the college was concerned that grid outages would severely disrupt the computer center operations upon which many of the college's functions rely. In place of installing a backup diesel or gas-fired generator, the board of the college approved the installation of a fuel cell that would not only provide back up power but also be able to operate in parallel with the grid and thereby reduce the college's electrical costs. Shortly thereafter, the college decided to approve a second fuel cell to provide power in parallel with the electric grid for a new student dormitory.

Both fuel cells would have the added benefit of supplying thermal energy in the form of hot water to the heating systems of the dorm and academic center thereby reducing the college's heating costs.

The only commercially available fuel cell at the time was the phosphoric acid fuel cell, known as the PC25 Model C, manufactured by ONSI. The thermal energy derived from the fuel cell allowed the dormitory designers to reduce the number of modular hot water heaters originally designed for the dormitory from eight (8) to four (4) thereby reducing the cost of the overall mechanical system.

Historically, small-sized conventional engine generators have not been able to deliver the efficiencies, availability potential, and reduced maintenance characteristics necessary to make dispersed generation a serious option. However, the inherent benefits of electrochemical energy conversion make fuel cells a potentially viable option for dispersed generation. This is due to the fuel cell's:

- reduced emissions,
- relatively high efficiency in the sub-megawatt size range,
- low noise and vibration levels,
- potential for longer times between scheduled and unscheduled shutdown maintenance than engine driven systems, and
- ability to perform scheduled quarterly maintenance while the power plant is operating.

The result of these attributes, such as with the PC25 Model C fuel cell power plant, is to now place base load generation within reach at the 200 kW range.

Fuel presently used by the phosphoric acid fuel cells is natural gas supplied by the local gas distribution company. Typical PC25 fuel cell emissions are as much as two orders of magnitude below the strictest air quality standards in the United States.

These new opportunities exist because the size of cogeneration systems is typically limited by the customer's thermal use and not by the customer's electric load. Because a fuel cell has a higher electric-to-thermal output ratio in comparison with a conventional engine generator, fuel cell technology tends to increase electric generation potential at moderately sized customers, as well as those with sensitive electric loads. For example, a phosphoric acid fuel cell such as the PC25 converts about 40 percent of the fuel input, on a lower heating value basis, into electric energy. An additional 40 percent is available as useful thermal energy. Examples of potential cogeneration applications now in reach using fuel cell technology can include hospitals, nursing homes, hotels, casinos, colleges, etc. For many of these loads, power reliability and quality are also becoming increasingly important.

For these reasons, dispersed generation locations at hospitals, computer centers, and the like are considered attractive market entry prospects for fuel cells. One mode of this application would be a premium power configuration where the fuel cell dispatches a full 200 kW to the grid during normal periods, and reverts to a grid independent supply for local customer loads during any grid interruption. This is exactly the situation of the academic fuel cell at Ramapo College.

How Fuel Cells Work

A fuel cell is an electrochemical device that directly converts chemical energy directly into electricity, in contrast to more conventional electric generation technologies such as natural gas turbines or fossil-fueled boilers. The latter generators convert the fuel's chemical energy first into thermal energy and then into shaft horsepower to produce electricity via a rotating generator. Thus, electric production from a fuel cell generally takes place at lower temperatures and is not subject to the efficiency limitations of normal generation. Electrochemical conversion is less environmentally intrusive due to lower emissions, as well as less noise and vibration because of the static nature of the process.

From a practical point of view, a fuel cell is much like a battery with one important difference. A battery is essentially a chemical energy conversion device with a fixed amount of fuel that runs down when the chemical energy stored in it, either during manufacture or from charging, is consumed. In contrast, a fuel cell has its chemical energy externally replenished and, thus, will continue to generate power as long as fuel continues to be supplied.

While fuel cells have been known since the 1800's, practical development began in the 1960's under the impetus of the Gemini and Apollo programs. Fuel cells occupied a key role due to their high energy density and because their by-product, water, was needed for drinking water and to cool spacecraft electronic equipment.

Fuel cells are classified by the type of electrolyte used inside the cell. Ranging from the lowest to the highest operating temperatures, current technologies are polymer, alkaline, phosphoric acid, molten carbonate, and solid oxide. Each technology has strengths and weaknesses, is subject to various internal and external complexities, such as reactant seals and materials of construction issues, and may be sensitive to various types of contaminants, etc. Thus, there is likely room for various types of fuel cells due to the spectrum of markets embedded in any overall commercialization program.

Phosphoric Acid PC25 Fuel Cell

Phosphoric acid fuel cells have been in continuous development since the mid-1960's incorporating substantial governmental and private industry funding. The major technology developer is International Fuel Cells and its ONSI subsidiary at United Technologies. Full commercial production of the 200 kW phosphoric acid fuel cell began several years ago with the ONSI PC25 Model A.

This extended effort has culminated in the commercial production of the PC25 Model C, the 200 kW phosphoric acid fuel cell covered in this report. This unit is a completely automatic commercial power plant designed for unattended outdoor operation. This initial commercial entry power plant is essentially a 40,000 pound (18,140 Kg), beige box 18 feet long x 10 feet wide x 10 feet high (5.5 m x 3.0 m x 3.0 m).

Unlike a battery, fuel is continuously supplied by a Fuel Processor to the cell's negative electrode, or anode. Concurrently, oxidant, which is oxygen from ambient air, is continuously supplied to the cathode or positive electrode. Like a battery, a fuel cell consists of two conductive plates separated by an insulating barrier containing an electrolyte. The reaction of hydrogen at the fuel anode is:

$$H_2 \longrightarrow 2H^+ + 2e^-$$

and of oxygen at the cathode, air side:

$$1/2\, O_2 + 2H^+ + 2e^- \longrightarrow H_2O$$

Since the electrolyte is an electrical insulator, the electrons are forced to travel in an external circuit and thereby produce useful power. In contrast, the hydrogen ions travel through the ironically conducting electrolyte to recombine with the electrons and oxygen to produce water vapor.

To encourage reasonable rates and efficiency of the reactions, a highly dispersed platinum catalyst is added to the anode and cathode adjacent to the electrolyte. In the phosphoric acid fuel cell, this is a paper-like material imprinted with a platinum/Teflon™ based "ink". The electrolyte assembly is essentially a 100 percent solution of phosphoric acid (H_3PO_4) dispersed within a porous silicon carbide layer. Phosphoric acid is considered a relatively mild acid from a chemical viewpoint.

Like a battery, the output voltage produced by a fuel cell decreases as more current flow is drawn by the circuit. Thus, higher current flows result in lower voltage. Typical operating conditions in a phosphoric acid cell are 210 amps per square foot (225 mA/cm^2) yielding around 0.60 volts per cell. In contrast, at an 80 percent reduction in current density the cell potential would increase to around 0.70 volts. These cells are stacked in series to provide the total voltage delivered by the cell stack.

Cell voltage is also a composite result of a number of other technical and practical factors. These include the amount of catalyst loading, temperature, pressure, reactant concentration, and the age of the cell. The latter arises from changes in the catalyst's physical composition or even by poisoning of reactive catalyst sites by contaminants.

The POWER SECTION of a practical fuel cell needs to generate electric power at reasonable voltage and current outputs. The production of 1400 amps at 155 volts DC requires an assembly of 256 cells with a cell area about 5.5 square feet (0.5 m^2). This assembly is called a fuel cell stack and, in case of the phosphoric acid PC25 Model C, is a package approximately 36 inches (0.9 m) square and 9.5 feet (2.9 m) tall.

Since the phosphoric acid cell stack operates at 350°F (177°C), a high purity circulating water loop within the power plant provides a means: to heat the unit to operating temperature during startup, to extract heat during operation, and to cool the stack at shutdown. Cell stack thermal management is provided by end cooler plates and intermediate separator coolers that are part of this circulating water loop. A typical power plant converts about 40 percent of the fuel's lower heating value to electricity and can supply about 40 percent of the balance as recoverable thermal energy for combined-heat-power customer use.

The phosphoric acid fuel cell, along with most others, uses gaseous hydrogen as the reactant. The FUEL PROCESSOR converts the natural gas or propane feed into a hydrogen rich fuel for the cell stack. The key component is the Reformer shown in Figure 5 that reacts steam and fuel, such as natural gas, within a supported nickel catalyst bed at 1650°F (900°C). This reaction is:

$$
\begin{array}{llllll}
CH_4 \text{ (methane)} & + H_2O & \text{———} & 3H_2 & + CO & \text{requires heat} \\
CO & + H_2O & \text{———} & H_2 & + CO_2 & \text{provides heat} \\
\hline
CH_4 \text{ (methane)} & + 2H_2O & \text{———} & 4H_2 & + CO_2 & \text{net heat}
\end{array}
$$

This reaction requires heat to warm the feedstock to reaction temperatures and to supply the net endothermic reaction. Spent fuel from the cell stack is routed to a burner within the reformer assembly to provide that heat.

Steam to react with the natural gas is generated by the cell stack's heating of recovered condensed water. As indicated in the figure, more water vapor is available than is needed for the reforming process due to oxidizing the hydrogen from the methane of the natural gas fuel.

A fuel cell stack produces unregulated, variable potential direct current due to its battery-like characteristic of lower voltage at higher current draws or as the cell stack catalyst ages. This variable voltage input is one of the criteria impacting the design of the POWER CONDITIONER block. Variable DC input from the cell stack is converted into a stable AC voltage of the proper quality, voltage, frequency, and phasing for customer and/or grid use. Also integrated in the Power Conditioner are controls and protective interlocks to assure that the power plant operates smoothly during load transitions and properly interfaces with the site's electrical network during perturbations caused by customer or grid events.

Any practical fuel cell power plant must be self contained and capable of fully automatic operation and of maintaining an appropriate grid/customer interface under all conditions. While the cell stack is an important part, it becomes just one of a number of other system components. Moreover, all of these components need to operate together in a fully integrated, unattended manner.

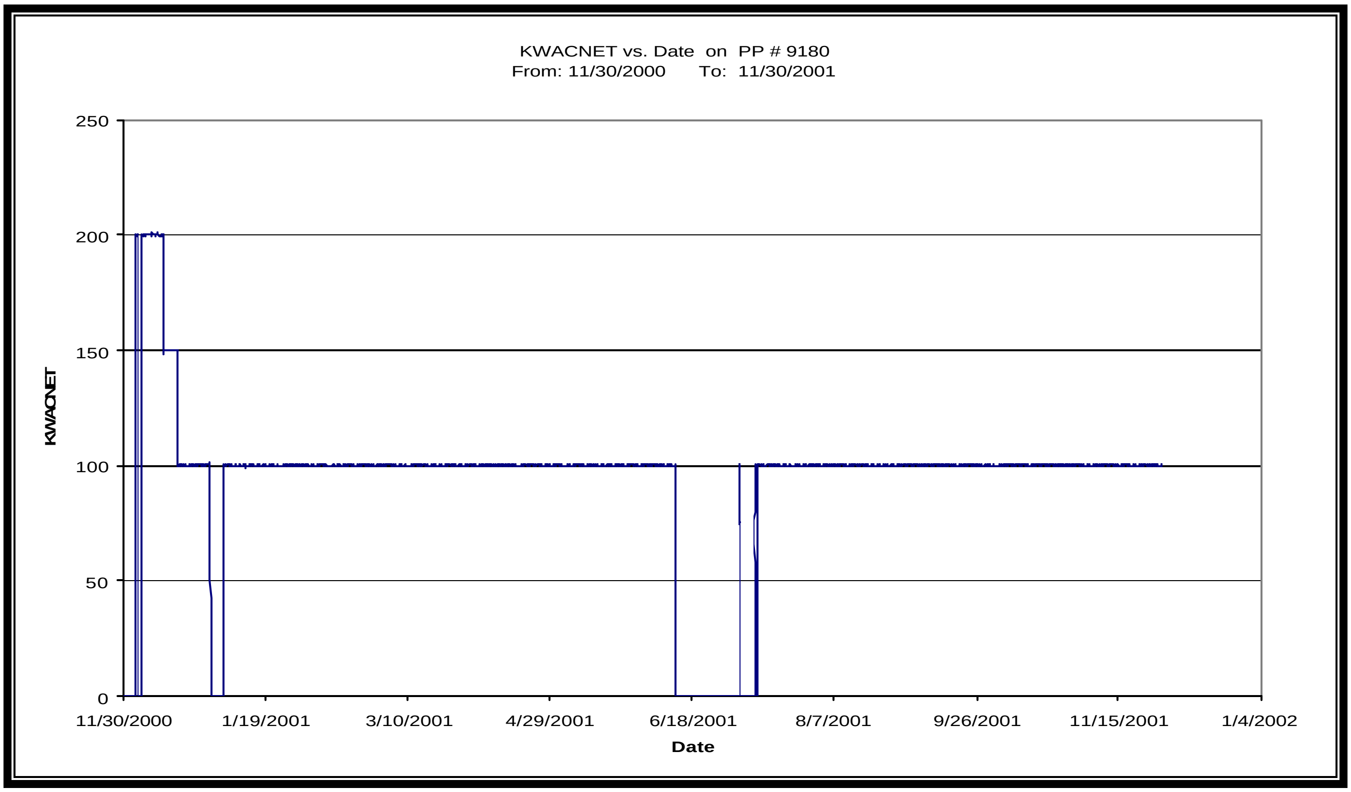
RESULTS and DISCUSSION

Academic and Dormitory Applications

Dormitory Fuel Cell - Electrical

The fuel cell power plant connects to the grid through the College's dormitory transformer.

Average electrical output from the power plant is shown below:



The unit was reduced in output to 100 kW when it was discovered that the unit was feeding power back into the grid during night and some weekend periods. Rather than feed power back into the grid during these periods it was decided to keep the unit operating at 100 kw continuously. As the graph above illustrates, the unit has operated reliably over the recorded period. Over the 12 month period the unit was shut down five (5) times. Three of these occurrences were planned while two were for high temperature of the stack. Minor repair of water supply piping and valve to the unit solved the high temperature problem.

Electric Grid Interconnect – Dormitory Fuel Cell

Electric grid interconnection at the Dormitory fuel cell location utilizes the customer side of the host's existing 208-to-grid transformer. Since the Dormitory was constructed using 208/110 lights and power and the fuel cell generates power at 480 volts, an onsite transformer was included adjacent to the power plant. An internal Motorized Circuit Breaker inside the Power Conditioner serves as the fuel cell's computer controlled grid disconnect. The Electric Utility also required an additional disconnect that essentially duplicates the protection provided by the unit in the PC25. Grid voltage is sensed on the out-board side of this MCB. In addition, grid interconnect current is sensed along with frequency, zero sequence voltage, and current. Local electric utilities have at times accepted the fuel cell power plant's built-in grid connect protocol without additional relaying. The power plant's built-in grid interconnection protocols have worked well. Originally, it was assumed that the fuel cell would be able to provide emergency back up power to the dormitory and to the adjacent dinning pavilion. Being a public building, the School Buildings Authority located in Trenton, NJ has the final approval on the use of fuel cells for emergency power. After many meetings, the Authority did not allow the fuel cell to serve as the emergency generator and a standard, natural gas fired, reciprocating engine generator was installed. Subsequently, the standards guide used by the Authority has been modified to allow use of a fuel cell for emergency lighting.

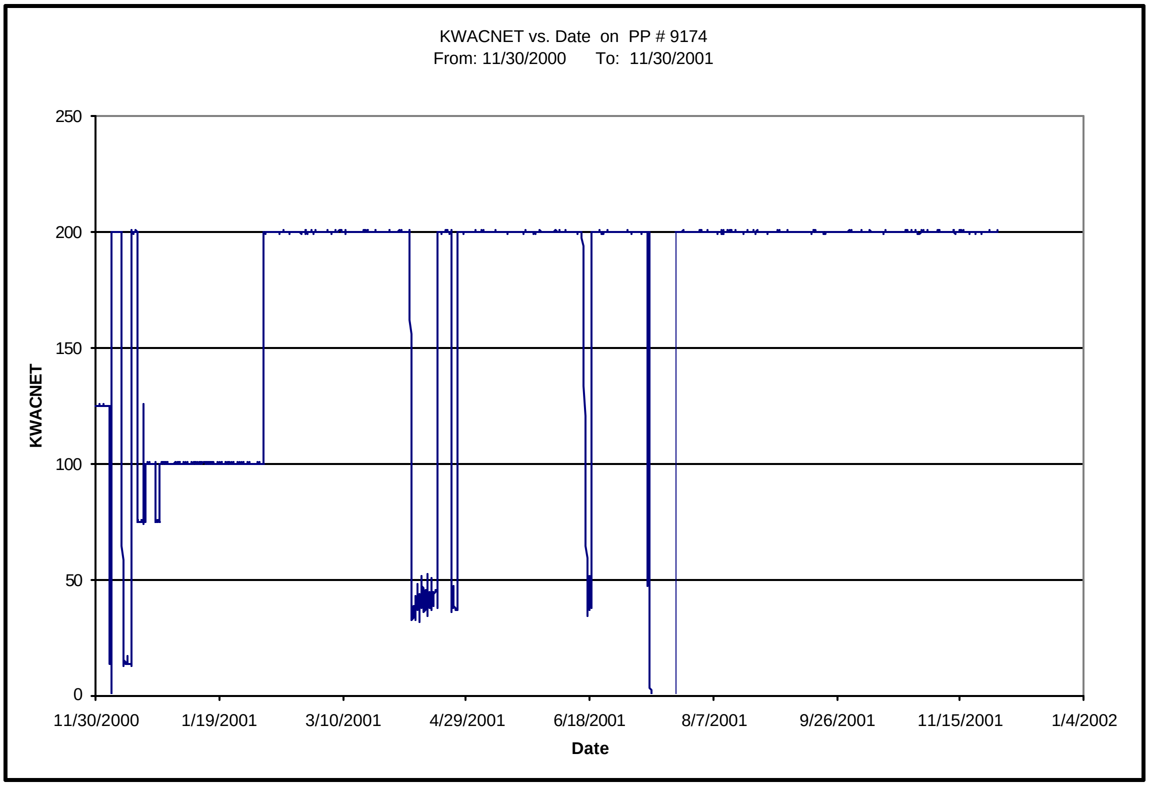
The dispatch controller within the power plant monitors these grid parameters, as well as others, and automatically halts inverter operation when a grid event occurs. If the event lasts longer than one-half second, the power plant automatically disconnects from the grid and, if the event is
unusually prolonged, reverts to idle. In an idle condition, the fuel cell remains fully disconnected from any outside electric system and operates independently to provide its own internal power for pumps, motors, controls, and for internal "keep hot" electric heat bootstrap loads. In effect, the fuel cell is then operating in a grid independent configuration, but unconnected to any external load.

Dormitory Fuel Cell – Thermal

The related thermal output is used to provide space heating and domestic hot water to the dormitory. Codes required the use of two separate double walled heat exchangers. The college disconnected the BTU meter shortly after commissioning of the fuel cell and hence no hard data is available. The facility personnel report that the four modular heaters only are activated during the morning winter period when the domestic hot water consumption peaks presumably because of student showering.

Academic Fuel Cell - Electrical

The academic fuel cell connects to the low side of the main transformer. The 13.3kv/480v transformer is rated at 1,000 kW and provides electrical power to the Main Core of Academic buildings totaling over 500,000 square feet. During normal operation the fuel cell operates in parallel with the electric grid. The use profile for the Dormitory Fuel Cell (#9174)is shown in the chart below.



The base electrical load for the core academic buildings served by the main transformer is 250 kW while maximum load is approximately 1,000 kW. In case of grid failure, the fuel cell is capable of disconnecting from parallel operation and to reconfigure itself within 10 seconds to provide power directly to the telephone center (30 kW), the computer center (70 kW) the cable TV station (30 kW), the cable TV station Roof Top Unit “RTU” (30 kW) and several small miscellaneous loads. In addition, a 60kw/90 minute UPS system that had been located in the Computer Data Center was replaced with a new UPS located in the transformer room. A functioning UPS system is necessary if the PC 25C is going to be operated in this mode because the fuel cell requires at least 5 second to internally reconfigure itself from parallel operation to independent power supply. The TV station, Computer center and parts of the telephone system without its own battery backups require a centralized UPS system if the objectives of the college were to be met. Without the UPS system the transition time from parallel operation to independent operation would be sufficient to disrupt the computer operation necessitating a rebooting of the system and loss of all files and information in random access memory.

It was anticipated that grid failure would only occur on average for 10 hours per year. The fuel cell has provided power to the core academic buildings for over 12 months with an operational availability as shown in the chart above. The majority of the reductions in power level of the fuel cell resulted from special modifications to the individual loads and interconnections during the first full year of operation.

Academic Fuel Cell – Thermal

The hot water from the academic fuel cell is piped to a double walled heat exchanger in the main mechanical room of the core academic building. The core academic building is normally supplied space heating through a converter located in the mechanical room. Steam is piped from a main boiler plant located about 200 yards from the mechanical room. A heat exchanger heats hot water that is pumped to perimeter units throughout the buildings. The hot water is normally supplied at 140 degrees F and returns at 110 degrees F depending on heat load. The thermal energy from the fuel cell is routed to a heat exchanger connected to the return line from perimeter units in the buildings. The hot water from the fuel cell heats the return water to approximately 130 degrees F. No BTU meters were installed to track the thermal utilization of the fuel cell. Because the heat load of the building is so large during the heating season and essentially zero during the non-heating season the college felt it was an unnecessary expenditure. Based on calculations of the fuel cells thermal output and the building load it is estimated that half the thermal energy from the fuel cell is being utilized over the entire year. It should be noted that the thermal energy utilization is highest when gas demand and gas prices are highest which will enable the college to negotiate better overall energy prices from suppliers.

Availability and Mean Time Between Forced Outages

Two measures of reliability are particularly useful: Availability and Mean Time Between Forced Outage (MTBFO). Availability is simply the percentage of overall calendar time that the unit is operating. Mean Time Between Force Outage is the length of time the unit can be expected to operate once it is running. These include average repair time and its relative variability from occurrence to occurrence, as well as the variation of the individual MTBFO lengths from run to run.

The availability for the Fuel Cells for the one year time-period represented in the charts above is as follows:
Computer Center Fuel Cell Availablility……………………………98.8 %
Dormitory Fuel Cell Availability……………………………………95.4 %

This was calculated by reviewing the operating data available for each of the units and considering the fuel cell available for electrical operation of it was producing at least 20 kw per hour. As noted in the charts incorporated above, the availability for both the Academic and Dormitory Fuel Cells exceeded expectations. It was not unusual for the units to operate months at a time before a scheduled maintenance shut down. Initially, the dormitory fuel cell was shutting down on high temperature or low water supply. This was solved by providing a separate, purified water supply to the unit. Initially this was not done because of the cost involved in piping an additional water pipe over 300 underground feet to the unit. For the operating period considered, the MTBFO was as follows:

Computer Center Fuel Cell MTBFO……………………………………..72 days
Dormitory Fuel Cell MTBFO……………………………………………124 days

Cost Benefit

This project suffered from cost overruns involving an expanded scope of work demanded by the customer and the difficulty in connecting the thermal and electrical connections of the Dormitory Fuel Cell.

Dormitory Fuel Cell - Capital Costs

The dormitory fuel cell was approved as the College was obtaining approval for the dormitory itself. The location of the fuel cell was changed three times by the college architect. When the location of the fuel cell was finally settled upon, it was determined after extensive review by all parties that the electrical connections could only be made to the transformer by entering from the east side of the building and the thermal connections could only be made to the hot water system by entering from the west side of the building. The dormitory architect was not able to modify the design due to time constraints and severe performance penalties and therefore two separate 300 foot trenches were required. Additional cost extras were incurred in retrofitting the thermal and electrical connections into the building. The mechanical and electrical rooms were designed with very little extra room. Only the removal of four (4) of the modular gas fired boilers allowed space for the heat exchanger and the thermal connections. An additional charge of about $45,000 was incurred in the installation of an emergency lighting generator. It was originally believed and represented to the college that the fuel cell could provide emergency lighting in case of grid failure. This was not approved by the Buildings Authority in Trenton, NJ until one year after installation. The college refused to pay for any of the extra charges.

Academic Fuel Cell – Capital Costs

Similar and even more sever cost overruns were experienced with the Academic Fuel Cell. A large centralized UPS and multiple independent connections to the TV station, telephone system and computer system were not included in the original budget and the college refused to pay for the cost overruns.

Capital Cost and Energy Savings– Totals

Total capital cost for both fuel cells including material, labor, design, engineering and project management totaled $2,150,000. The original budget was for $1,600,000. The fuel cells themselves cost approximately $620,000 each. After the purchase of the fuel cells the manufacturer revised its pricing and raised the price to $875,000 per cell.

Total annual savings for the Academic Fuel Cell which has operated close to the 200 kw design capability is estimated to be $125,000. Similarly, total savings for the Dormitory Fuel Cell is about $65,000 per year. Combined savings compared to the total installed cost less the Federal Government incentive results in a simple economic payback of approximately nine years.

Cost/Benefit Summary

Activity	Cost Dorm Unit	Cost Computer Center Unit	Total Cost
Fuel Cell Units (number of Units)	1	1	2
Fuel Cell Unit Cost ($/Unit)	$ 620,000	$ 621,000	$ 1,241,000
Installation Costs	$ 400,000	$ 534,000	$ 934,000
Total Capitalized Plant Costs	$ 1,020,000	$ 1,155,000	$ 2,175,000
First Year Fuel Cost(Note 1)	$ 34,652	$ 55,502	$ 90,154
First Year Maintenance Costs(Note 2)	$ 14,000	$ 18,000	$ 32,000
First Year Kwh generated	812,476	1,478,799	2,291,275
Gas Cost per Kwh	$ 0.043	$ 0.038	$ 0.039
Maintenance Cost per Kwh	$ 0.017	$ 0.012	$ 0.014
Total Variable Cost per Kwh	$ 0.060	$ 0.050	$ 0.053

Note 1: Ave. Fuel Costs $5.01/MCF Dorm

Note 1: Ave. Fuel Costs $4.40/MCF Computer Center

Note 2: Maintenance Cost allocated per contract

Reliability

After the initial shake out period the units have operated very reliably. The units are monitored by the fuel cell manufacturer on a 24/7 basis. Any upsets from either the grid or the fuel cells result in an alarm. Simple errors and upsets can be reset remotely and the units brought back on line. The college has a service contract to provide periodic maintenance for the units.

Thermal Output

The fuel cells are configured to provide hot water at 140 degrees F. As previously explained, the BTU meter of the Dormitory fuel cell was disconnected and a BTU meter was not included in the Academic Fuel Cell. Based on discussions with college facility personnel, the dorm fuel cell provides the majority of the space heating and domestic hot water needs except during peak periods. During summer periods almost all of the thermal energy is exhausted by the fan coolers installed next to the fuel cell. Similarly, during the heating season all the thermal energy of the Academic Fuel Cell is utilized while very little thermal energy is used during the summer periods.

Certification

" McBride Energy Company certifies that the fuel cells have been in operation for 1 year and the activity required under the agreement with DOE is complete."

Conclusions

It can be concluded that the fuel cells are a reliable and efficient source of electrical and thermal energy although they are extremely costly power plants. The cost of installation exceeded original projections for reasons previously covered. Part of the reasons are due to incomplete contracts with the college while other reasons are due to the fact that the Dormitory was designed prior to the fuel cell approval and it was very expensive to install the unit. The large number of independent tie-in locations that the academic fuel cell has upon grid failure and the associated cost of labor and material caused the cost overruns.

The wide fluctuations in the cost of gas has also effected the economics of the project although with the current reduction in gas costs, the overall cost of electric power from the fuel cells are less than initially projected.

The ability of the fuel cell to reconfigure itself upon grid failure is a major advantage of the units. This ability enables operation of critical loads without the cost and pollution of backup generators. The State of New Jersey has also recently amended their building code for public building to allow fuel cells to provide emergency lighting. This will improve the economics in the future.

In summary, the contractual, communication and timing of this project were by far the most problematic part of the project while the fuel cells, as power plants using established but novel technology were not an issue.